Hall effect , Hall Coefficient and its applications

Definition: If a current carrying conductor (or semiconductor) is placed in the magnetic field perpendicular to the direction of current, the magnetic field exerts a transverse force (Lorentz force) on the moving charge carriers which tends to push them to one side of the conductor. A build-up of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. This voltage is called **Hall voltage (V_H)** and this effect is called the **Hall Effect**.

Consider a conductor having rectangular cross section and carrying a current I along X-axis. When uniform magnetic field is applied along Z-axis, Lorentz force which is along Y axis, acts on the electrons which causes the electrons to accumulate along negative Y-axis (Figure 1).

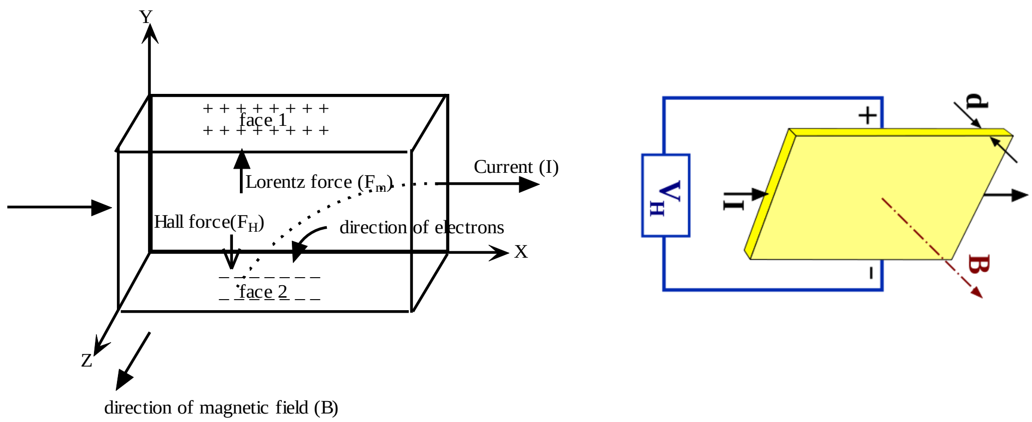

Figure 1: Origin of Hall effect

The Lorentz force on the electrons is given by:

$$\overrightarrow{F_m} = q(\overrightarrow{v_d} \times \overrightarrow{B})$$

Here, $\overrightarrow{v_d} = -v_d\,\hat{i}$ (since velocity of electron is opposite to the direction of current)

$$\overrightarrow{B} = B\,\hat{k} \text{ and } q = -e$$

Hence, $\overrightarrow{F_m} = -e(-v_d\,\hat{i}) \times B\hat{k} = -ev_d\,B\,\hat{j}$

Since electrons are accumulating along negative Y axis (face 2), then positive Y axis will be positive due to induction which causes a potential deference (called Hall voltage). Here the Hall field (E_H) developed is along negative Y-axis. The potential difference causes an electric force on electrons which oppose the

Lorentz magnetic force. The accumulation process continues until the electric force (called Hall force) balances the Lorentz magnetic force.

i.e. $F_H = F_m$ and if E_H is Hall electric field, then

$$F_H = e\,E_H$$

Now at the equilibrium the **magnitude** of Hall force and Lorentz force will be equal,

i.e. $e\,E_H = e\,v_d B \Rightarrow E_H = v_d B$

Current density can be given as

$$J_x = -nev_d$$

then , $\frac{E_H}{J_x} = \frac{-B}{ne} \Rightarrow E_H = R_H B J_x$

Here R_H is called Hall coefficient and given by:

$$\boxed{R_H = \frac{E_H}{BJ_x} = -\frac{1}{ne}} \qquad \text{---(1)}$$

Hall coefficient is negative if charge carriers are electrons and positive if charge carriers are holes.

All the three quantities i.e. E_H, B and J_x can be measured and hence the Hall coefficient and charge carrier density can be calculated.

Applications of Hall effect:

(1) Determination of semiconductor type: For n-type semiconductor the Hall coefficient is negative and for p-type Hall coefficient is positive.

(2) Calculation of charge carrier concentration: If Hall coefficient is known then charge carrier concentration can be calculated as: $n = \frac{1}{R_H e}$

(3) Determination of charge mobility: If the conduction is one type of carriers i.e. due to electron, then conductivity can be given as: $\sigma = ne\mu$

or $\mu = \sigma / ne = \sigma R_H$

If conductivity is known, the charge mobility can be calculated.

(4) Measurement of magnetic flux density: Since Hall voltage V_H is proportional to the magnetic flux density **B** for a given current **I** through the specimen, the Hall effect can be used as the basis for the design of a magnetic flux density meter.